# MAPPING VISITOR IMPACTS WITH GIS AT OREGON CAVES

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**Abstract**

Managing visitor impacts is a major issue in all show caves, where thousands of visitors annually can have a profound effect on a cave's scientific, ecological, and aesthetic integrity. Visitor-impact mapping, a monitoring technique first presented by Bodenhamer (1996) was joined with Geographic Information Systems (GIS) to assess the condition of Oregon Caves and its resources. Hazard and fragility were assessed throughout the cave to map areas of potential impact. Data on the presence and severity of more than 20 readily visible impacts were collected along heavily traveled corridors. Features of interest or concern were photo-inventoried, including paleontological sites, and photos were hyperlinked to GIS layers to establish monitoring. These inventories and assessments helped identify significant impacts, define off-trail access zones, and plan for off-trail caving tours. GIS-based visitor-impact mapping helps balance cave use and protection.

Key words: show cave management, GIS, hazard mapping, fragility mapping, photo-inventory, Oregon Caves, Oregon

## Introduction

Visitor-impact mapping is the technique of mapping impacts and resources to monitor the condition of a cave (Bodenhamer 1996). In 2005-07, resource management staff and interns at Oregon Caves engaged in a project to assess and monitor impacts using Geographic Information Systems (GIS). The goal was to determine the severity and extent of impacts and whether impacts are becoming more severe over time. The objective of this project was to systematically and comprehensively collect and integrate photos; visitor-caused, negative impacts; and cave resources in a geodatabase to:

- Quantify impacts,
- Monitor the condition of resources, and
- Better inform management decisions.

The approaches to mapping visitor impacts were:

- Assessment of hazard and fragility,
- Inventory of impacts,
- Photo-monitoring and inventory,
- Survey of paleontological sites, i.e. bones and other animal evidences, and
- Mapping of lampenflora, i.e. nonnative plant growth, including algae and cyanobacteria, around tour path lights.

## Oregon Caves

Oregon Caves National Monument is located in the Siskiyou Mountains in southwestern Oregon between Interstate-5 and the Pacific coast. The main cave entrance is situated at an elevation of 1,219 m. Oregon Caves is a marble cave that showcases regional geology and is a habitat to at least seven endemic macroinvertebrate species. Additionally, the cave contains many significant paleontological resources, including salamander bones, bear scratches, bear bones >50,000 years old, and the remains of a jaguar >38,600 years old.

The total surveyed length of the cave is 4.8 km. An average of 48,000 visitors tour the cave annually using a 1-km developed route. The off-trail caving tour, which was offered once a week to the public for the second time in summer 2007, follows a route through about 200 m of off-trail cave passages, including passages that were part of the old tour route.

Visitor impacts in the cave include damage to resources that are deemed significant in the study of earth processes and natural history, such as animal remains, geological features, and sediment deposits, ecologically significant impacts resulting from tour path lighting, lint deposition, sediment compaction and translocation, and historic entrance and passage enlargement, and the aesthetic devaluation of cave formations from souvenir collecting, illegal graffiti, or excessive touching.

## Background

At the time this project was being formulated, the need to increase understanding and monitoring of impacts in Oregon Caves was underscored by planning for off-trail caving tours. Nineteen fixed-point, photo-monitoring stations had been installed in 2003 along the developed tour path, a portion of the proposed caving tour route and at cave entrances. Bodenhamer (1996) showed that photo-monitoring supplemented by visitor-impact mapping can provide a more complete picture of the condition of a cave and its resources. However, efforts to intensively quantify and monitor impacts through mapping have been largely focused on relatively pristine or undeveloped caves, not show caves (Bodenhamer 1996, Bunting and Balks 2001).

A GIS had already been established for Oregon Caves before the project. It included layers of survey stations, survey shots, and photo-monitoring stations, and a table of resource inventory data. Though GIS is widely used to map caves and manage inventory data, assessing and monitoring impacts in caves are only beginning. Notably, Sainsbury (2005) used GIS to hyperlink photos to a GIS layer of monitoring stations in order to evaluate impacts and their spatial pattern.

## Ethics

In preparation for fieldwork, resource management staff and interns outlined minimum-impact protocols. These included confining all travel and equipment to the most impacted path, handing off an item only when the receiver has verbally affirmed it is in her/his grip, and planning ahead to complete work in as few trips as possible. In the cave, staff and interns practiced low-impact caving techniques and packed a small bag to collect trash.

## Materials and Methods

*Assessment of Hazards and Fragility*. An assessment of hazards and fragility was conducted to map areas of potential impact. Passages were classified according to the hazard they pose to the caver and their fragility, i.e. vulnerability to damage. The assessment was conducted for areas defined by survey shots, i.e. the portion of passage between two survey stations. Data collected in the cave were input into a GIS layer of survey shots using ESRI ArcPad® on a Pocket PC. Hazard was assessed based on vertical exposure, instability of the passage, and caving equipment and expertise required to negotiate the passage (Table 1). Fragility was assessed as the average of four equally weighted ratings: resource condition, proximity to fragile resource, resource value, and density of breakable formations (Tables 2-5).

*Impact Inventory*. An inventory of more than 20 readily visible impacts was conducted along heavily traveled corridors to provide a baseline of information to better understand the nature of impacts as well as a starting point for restoration and mitigation. Cave resource inventories are conducted for similar purposes (Kovarik and Kambesis 2006). Modeling the methodology of Oregon Caves' resource inventory from the 1990s, impacts were inventoried for areas defined by their proximity to survey station markers and extending outward to a boundary halfway in each direction to adjacent markers. Data collected in the cave were input into a GIS layer of survey stations using ESRI ArcPad® on a Pocket PC. Severity was based on percentage categories or how widespread the impact (Table 6). The inventoried impacts included various manifestations of disturbance to cave sediments and speleothems, evidence of improper caving, and impacts resulting from tour paths and heavy visitation.

*Table 1 Hazard Rating Criteria*

| | Criteria |
|---|---|
| **0** | Paved, clearly marked pathway. Lighted trail. Some stooping, but no crawling is necessary. |
| **1** | No known loose ceiling rocks. Well-defined main passageways with only dead-end lateral passages. No drop over 3 m. Basic caving equipment is required. |
| **2** | Maze-type passageways. Vertical drops up to 9 m. Loose rocks on ceilings >2 m in height. No known loose rocks on passages <2 m. Balanced rocks on uneven floor. |
| **3** | Vertical drops over nine m. Loose ceiling rocks in crawlways <1.5 m. |

*Table 2 Fragility Rating Criteria: Resource Condition*

| Rating | Resource Condition | Criteria |
|---|---|---|
| 4 | Pristine | 100% of the cave features in the area are undamaged. |
| 3 | Very Good | 75 – 99% of the cave features in the area are undamaged. |
| 2 | Good | 50 – 74% of the features in an area are undamaged. |
| 1 | Poor | Less than 50% of the features in an area are undamaged. |

*Table 3 Fragility Rating Criteria: Proximity to Fragile Resource*

| Rating | Proximity to Fragile Resource | Criteria |
|---|---|---|
| 4 | Must Contact | Resource must be touched to pass. |
| 3 | Likely Contact | Resource will probably be touched. |
| 2 | Possible Contact | It is possible to touch resource along path, but unlikely. |
| 1 | Not Possible | There is no way to touch or damage the resource. |

*Table 4 Fragility Rating Criteria: Resource Value*

| Rating | Resource Value | Criteria |
|---|---|---|
| 4 | Very High | The resource is regionally rare, very aesthetic, or may be of great scientific interest. |
| 3 | High | The resource is uncommon, aesthetically pleasing, and may have some scientific value. |
| 2 | Medium | Resource is pretty, but has little scientific value. |
| 1 | Low | Resource is very common. |

*Table 5 Fragility Rating Criteria: Density of Breakable Formations*

| Rating | Density of Breakable Formations | Criteria |
|---|---|---|
| 4 | High Concentration | High number of breakable formations. |
| 3 | Medium Concentration | Moderate number of breakable formations. |

*Table 6 Severity Rating Criteria*

| Rating | Severity of Impact | Criteria |
|---|---|---|
| 4 | Extreme | 60% - 100% extent of impact OR further impacts would not register |
| 3 | Heavy | 30% - 60% extent of impact OR multiple impact detections, though further impact still possible |
| 2 | Moderate | 10% - 30% extent of impact < 30% OR impact detected by several instances, but not widespread |
| 1 | Light | <10% extent of impact OR impact only detected by one minor instance |

*Photo-monitoring and Inventory*. High-resolution digital photos were retaken at all (19) fixed-point photo-monitoring stations. Other resources and sites of interest or concern were captured in a photo inventory, e.g. landmark formations, rare or exceptionally pristine resources, passages or features already showing impact, or areas in which increased visitation was anticipated. Photos were taken with an object for scale (pencil, keys, etc.). The nearest survey station marker to the photo subject was recorded. Photo-monitoring and inventory were conducted with a Canon Digital Rebel XT camera.

*Paleo Survey*. All known paleontological sites and others discovered during fieldwork were surveyed from the nearest convenient survey marker with a Suunto compass and inclinometer with a Disto laser distance meter. Each site was photographed in detail and context with an object for scale (pencil, keys, etc). Photos were taken with a Canon Digital Rebel XT. Following recommendations of Toomey (2006), site descriptions included the quantity, color, and size of the paleontological items, their context, location and, if feasible, their supposed origin. Additionally, the condition, likelihood of disturbance, and value of the paleo site were assessed. Descriptions, assessments and survey data were input into a spreadsheet on a Pocket PC. A labeled flag or surveyors tape was placed at paleo sites most likely to be disturbed by foot traffic (Figure 1).

*Lampenflora Mapping*. The presence and amount of lampenflora were attributed in a GIS layer of cave lights using ESRI ArcPad® on a Pocket PC.

*Figure 1 Paleontological resources were surveyed, described, and photographed with an object for scale. Sites were flagged when in danger of disturbance.*

## Results

*Assessment of Hazards and Fragility*. Maps were created to highlight hazardous or fragile areas (Figures 2–3). Caving zones were mapped based on combined hazard and fragility (Figure 4). The Oregon Caves Subsurface Management Plan (Department of the Interior, National Park Service 2005) clarifies access restrictions for each zone (Table 7). Similar criteria-based classifications are used to determine access for caves in Canadian national parks (Horne 2006).

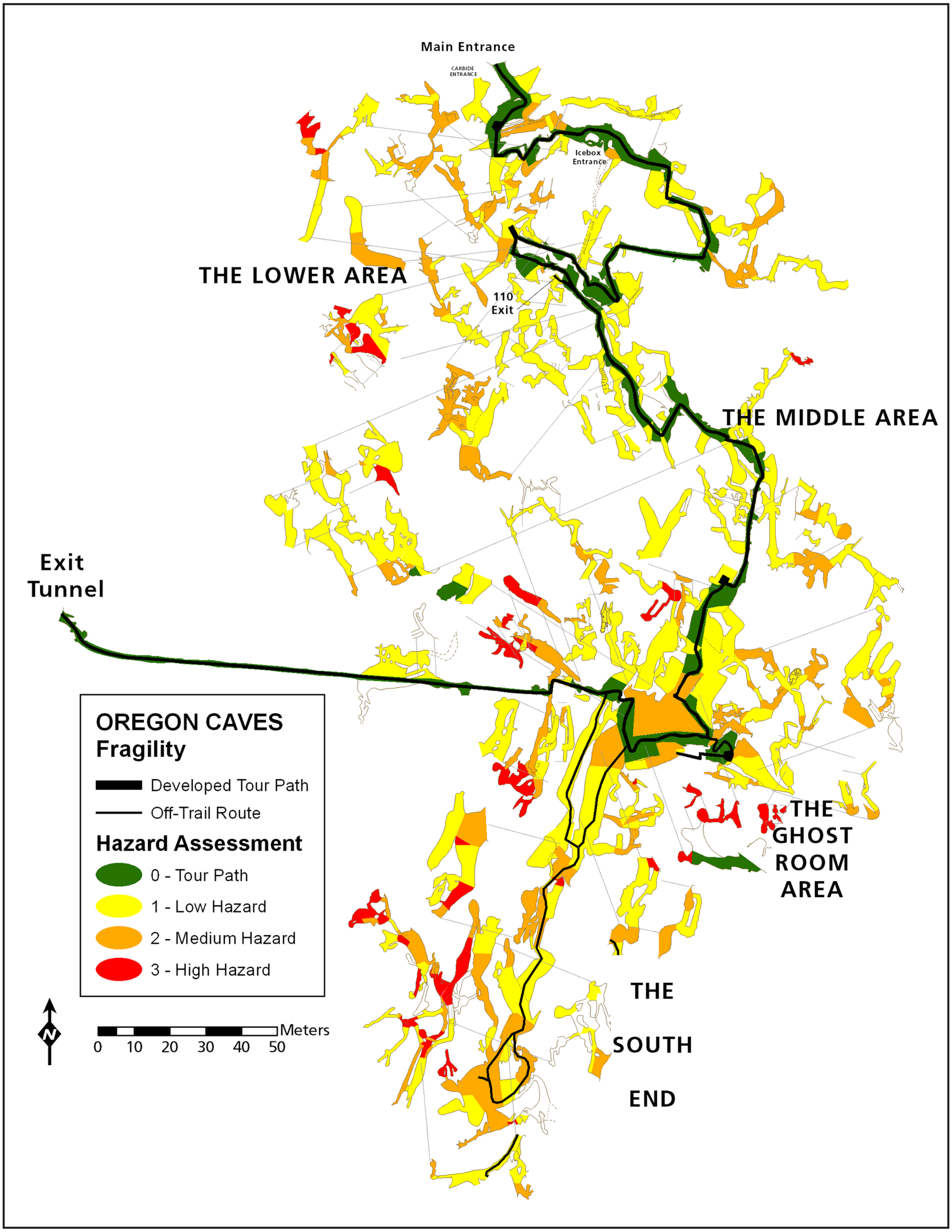


*Figure 2* *Hazard Map. A rating of zero does not mean that there are no hazards at all.*

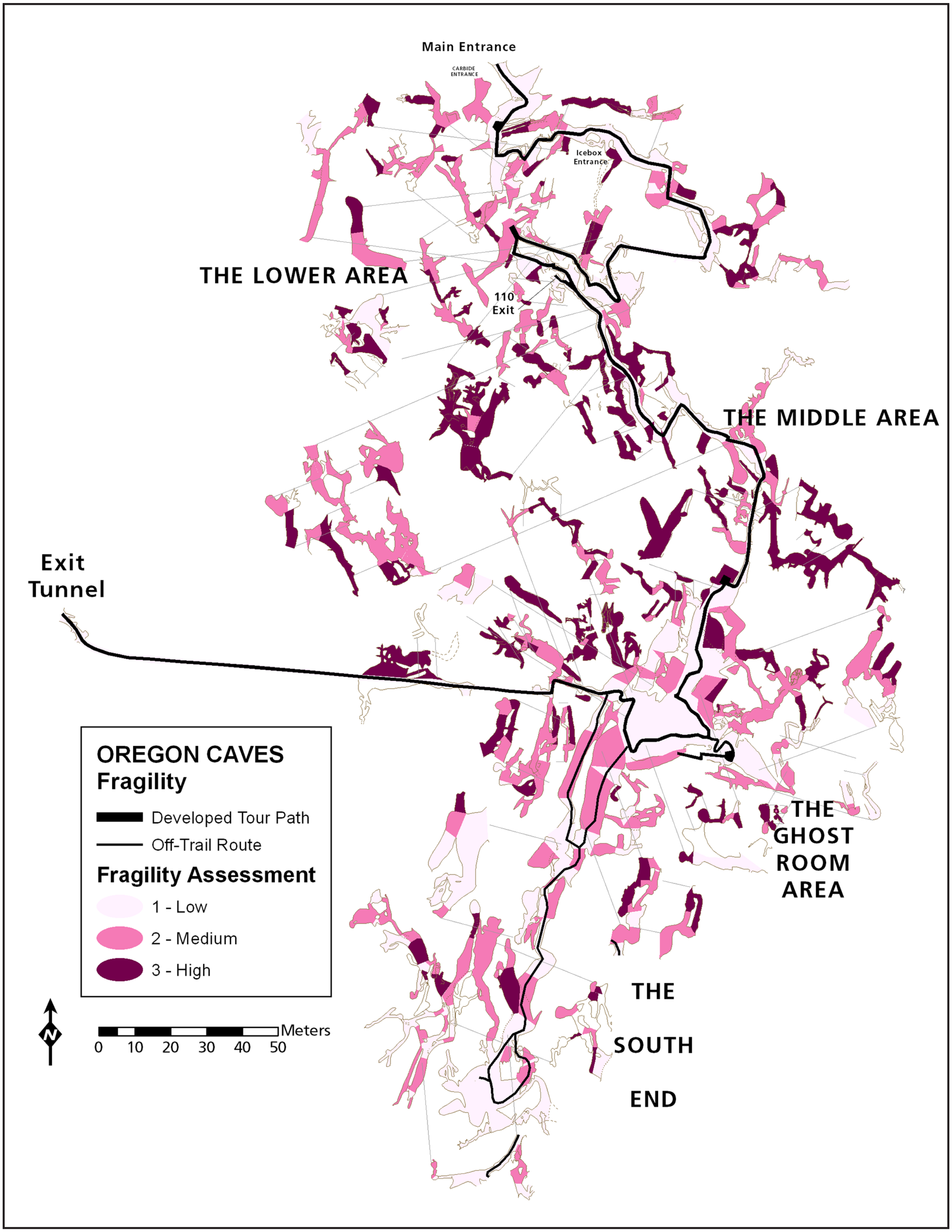


*Figure 3 Fragility Map.*

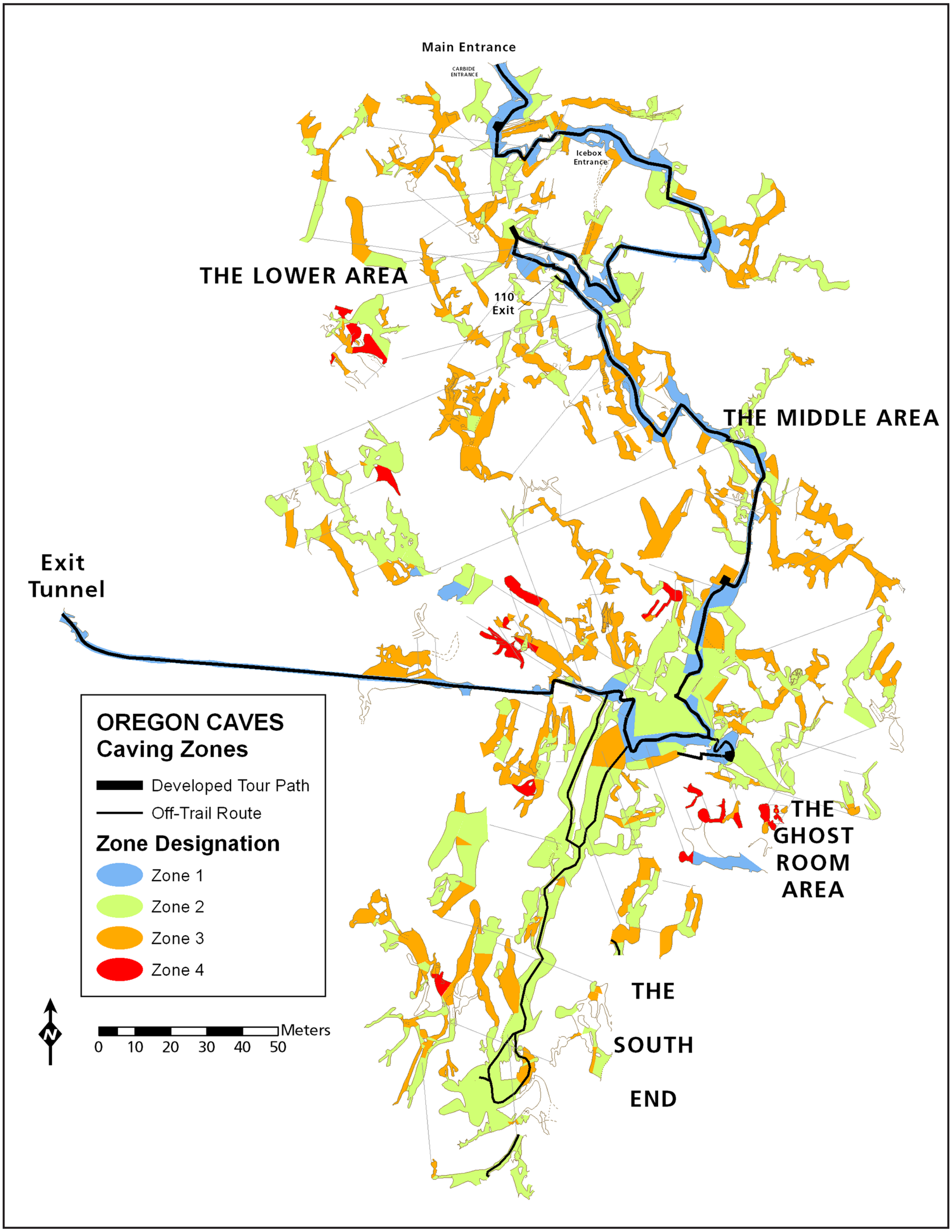


*Figure 4* *Caving Zones Map. Cavers must obtain the permit required for the most restricted zone they visit on their trip*

*Table 7 Caving Zone Descriptions (Source: 2005 Oregon Caves National Monument Subsurface Management Plan)*

| | Description |
|---|---|
| 1 | These developed areas include most public use areas that provide visitors with comfort and convenience (e.g. hard surfaced trails, handrails, and electric lights). No special clothing, equipment, knowledge or skills is needed. National Park Service (NPS) staff must accompany all visitors. |
| 2 | These areas may be visited by permit without an NPS escort. Permitees are responsible for providing their own equipment. Evidence of incompetence, previous cave abuse or disregard for park regulations are grounds for denying a permit. All members of the group will stay within the trail zone bounded by tape. |
| 3 | These areas may be visited only when scheduled in advance and when a designated NPS trip leader accompanies the visitor. |
| 4 | To obtain access, the superintendent must approve a collection permit. The researcher must show in writing how potential damage to resources from research in a specific part of a cave will be more than balanced by knowledge gained that would protect park resources. Zone 4 designation does not exclude administrative entry to monitor research activity and impacts upon these caves. All newly discovered caves or cave passages will be initially assigned a Zone 4 designation. |

*Table 8 Hazard-Fragility Results (% of survey shots)*

| Classification | Hazard | Fragility | Zone |
|---|---|---|---|
| 0 | 9 | -- | -- |
| 1 | 54 | 33 | 9 |
| 2 | 25 | 37 | 44 |
| 3 | 9 | 28 | 40 |
| 4 | -- | -- | 4 |
| undetermined | 4 | 3 | 4 |

*Table 9 Impact Inventory Results: Detection Rate (% of survey markers where impact was possible to occur)*

| Ranking | Developed Tour Path (1 km) | Off-Trail Caving Tour Route (202 m) |
|---|---|---|
| 1 | Polishing/Darkening (97%) | Sediment Compaction (97%) |
| 2 | Path Cutting (95%) | Polishing/Darkening (94%) |
| 3 | Lint (85%) | Flowstone Surface Scratches (93%) |
| 4 | Hair (84%) | Sediment Translocation (71%) |
| 5 | Soda Straw Breakage (79%) | Sediment Erosion (63%) |
| 6 | Sediment Compaction (76%) | Vermiculation Smearing (50%) |

| | | |
|---|---|---|
| 7 | Flowstone Surface Scratches (71%) | Crystal Wall Damage (50%) |
| 8 | Stalactite Breakage (68%) | Soda Straw Breakage (45%) |
| 9 | Trash (56%) | Stalactite Breakage (45%) |
| 10 | Crystal Wall Damage (50%) | Hair (43%) |
| 11 | Drapery Breakage (49%) | Lint (37%) |
| 12 | Stalagmite Breakage (39%) | Drapery Breakage (33%) |
| 13 | Gunnite (39%) | Path Cutting (26%) |
| 14 | Sediment Translocation (36%) | Imprint in Wall Mud (20%) |
| 15 | Vermiculation Smearing (29%) | Sediment Transfer to Speleothem (20%) |
| 16 | Sediment Erosion (26%) | Trash (14%) |
| 17 | Imprint in Wall Mud (9%) | Gunnite (14%) |
| 18 | Sediment Transfer to Speleothem (9%) | Stalagmite Breakage (13%) |
| 19 | Pool Damage (7%) | Pool Damage (6%) |
| 20 | Crystal Pool Damage (0%) | Crystal Pool Damage (0%) |
| AVERAGE | 50% | 42% |

*Table 10 Impact Inventory Results: Average Severity (% of survey markers where impact was detected)*

| Ranking | Developed Tour Path (1 km) | Off-Trail Caving Tour Route (202 m) |
|---|---|---|
| 1 | Path Cutting (3.5) | Path Cutting (3.4) |
| 2 | Soda Straw Breakage (3.1) | Stalactite Breakage (3.4) |
| 3 | Stalactite Breakage (3.1) | Sediment Compaction (3.1) |
| 4 | Drapery Breakage (3.0) | Stalagmite Breakage (3.0) |
| 5 | Stalagmite Breakage (2.9) | Soda Straw Breakage (3.0) |
| 6 | Sediment Compaction (2.9) | Polishing/Darkening (2.8) |
| 7 | Crystal Wall Damage (2.8) | Sediment Erosion (2.8) |
| 8 | Polishing/Darkening (2.7) | Pool Damage (2.5) |
| 9 | Flowstone Surface Scratches (2.5) | Flowstone Surface Scratches (2.4) |
| 10 | Pool Damage (2.4) | Drapery Breakage (2.3) |
| 11 | Gunnite (2.3) | Gunnite (2.2) |
| 12 | Imprint to Wall Mud (2.3) | Sediment Translocation (2.0) |
| 13 | Vermiculation Smearing (2.1) | Vermiculation Smearing (1.9) |
| 14 | Lint (2.0) | Crystal Wall Damage (1.5) |
| 15 | Sediment Erosion (1.8) | Lint (1.5) |
| 16 | Hair (1.8) | Imprint to Wall Mud (1.4) |
| 17 | Sediment Translocation (1.6) | Hair (1.4) |
| 18 | Trash (1.4) | Sediment Transfer to Speleothem (1.3) |
| 19 | Sediment Transfer to Speleothem (1.3) | Trash (1.2) |
| 20 | Crystal Pool Damage (0.0) | Crystal Pool Damage (0.0) |

The majority of off-trail passages were classified "low hazard" and "low or medium fragility," and therefore categorized zone 2 or 3 (Table 8). In most cases off-trail visits will need to be scheduled in advance, according to zone 3 regulations, because most routes taken will pass through at least one zone 3 area. Passages that were classified as both "high hazard" and "high fragility" were usually domes, several of which require roped ascent. A few zone 4 passages are bottlenecks to farther reaches of the cave. Network analysis tools provided in ESRI ArcGIS Desktop® can help plan routes of least hazard and fragility through the cave (Ohms 2003).

*Impact Inventory*. Data on the presence and severity of impacts along the developed tour path and the off-trail caving tour route were summarized (Tables 9-10). Polishing/darkening was the most frequently detected impact on the tour path, and second most frequent on the off-trail route following sediment compaction. Other abundant impacts along the developed tour path were related to speleothem breakage and human-caused debris.

The impact inventory was completed for the off-trail route before the first off-trail tour season. Sediment compaction was usually rated "heavy" or "severe" when detected. Scraping on sediment floors and sediment translocation, sometimes referred to as sediment tracking or transfer, were frequently detected. Flowstone surface scratches were observed at 90 percent of the areas where it was possible, as were polishing/darkening and sediment compaction. Surface scratches are an enduring impact from rubble, most of which was hauled out in the 1980s and 90s.

*Photo-monitoring and Inventory*. Photos retaken at fixed-point photo-monitoring stations in 2006 revealed no new impacts when compared to the baseline from 2003. Over 80 other resources or sites were captured in the photo inventory, and additional photos from park files were incorporated into the photoset. A photo-mosaic of a flowstone formation was created in order to read its entire collection of historic signatures and monitor vandalism. To manage cave photos, a polygon GIS layer of the cave was divided into sections to represent areas defined by proximity to survey markers. Photos were hyperlinked to this GIS layer, allowing photosets to be retrieved for specific locations and directly compared (Figure 5).

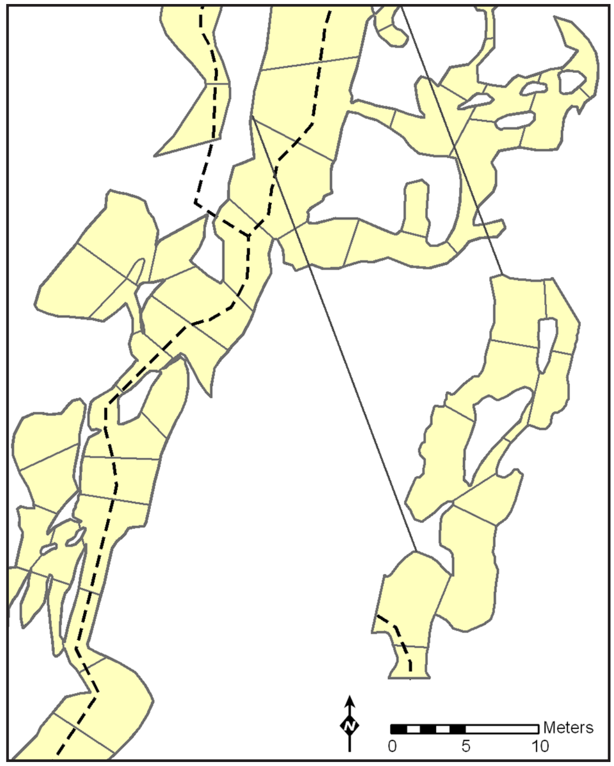


*Figure 5* *A GIS layer of the cave was divided into sections based on proximity to survey marker. Photos that are hyperlinked to this GIS layer can be retrieved by location.*

*Paleo Survey*. The paleo survey resulted in a baseline of over 140 paleo sites. The majority appeared to contain rat or bat bones. Several contained large mammal bones. A GIS layer of paleo sites was created from survey measurements that were processed with Compass software. Paleo survey photos were hyperlinked to paleo sites in this layer.

*Lampenflora Mapping.* In 2007 mapping revealed that slightly more than 60 percent of cave lights harbored lampenflora (Table 11). Recessed lights, which account for 40 percent of cave lights, supported significantly less lampenflora than other light types.

## Planning for Off-trail Tours

Visitor-impact mapping was completed along the off-trail caving tour route in 2006 to help determine how to conduct off-trail tours and protect cave resources along the route. No part of the off-trail route was classified high hazard or high fragility, but a significant portion was classified medium hazard and medium fragility (Figures 2–3). Haz-

*Table 11 2007 Algae Survey Results (% of lights)*

| | TOTAL SURVEYED (293 lights) | Spotlight (151 lights) | Recessed (117 lights) | Mini (14 lights) | Globe (11 lights) |
|---|---|---|---|---|---|
| No Algae | 39 | 17 | 71 | 29 | 0 |
| Algae Present | 61 | 83 | 29 | 71 | 100 |
| **Amount of Growth** | | | | | |
| Light | 49 | 44 | 85 | 40 | 0 |
| Moderate | 27 | 31 | 9 | 40 | 27 |

ards include slippery muddy steps and footholds, uneven floor surfaces, and potentially claustrophobic squeezes. Except for passages historically used for tours, the off-trail route is absent of speleothems, but other fragile resources include bones, wall crystals, and sediment pools. Results from the impact inventory suggested that polishing/darkening, sediment compaction and translocation, and hair were the impacts most likely to increase due to off-trail tours.

Many hazards were addressed by ensuring that cave guides were trained to emphasize safe caving techniques, such as three points of contact, and follow protocols for safely leading visitors through route, such as climbing or descending vertical areas one caver at a time. A hazard of particular concern—a scramble down some muddy rocks with a potential fall of about 3 m—was alleviated by placing rocks to create additional footholds.

Guides were trained to proactively ensure that visitors practice low-impact caving techniques in fragile areas, and trailing guides were trained to check on key resources along the way. Twelve bone sites were documented in the paleo survey, and 11 were flagged for protection. Footholds and tight areas, which may show signs of increased polishing, were photo-inventoried along with landmarks and fragile resources. Flagging was placed to call attention to crystals and pools. Other measures of protection included flagging path boundaries and purchasing souvenir bandanas for visitors to secure loose hair.

## Discussion

The visitor-impact mapping methods employed at Oregon Caves can be adapted for other caves. The two-pronged strategy for mapping visitor impacts in any cave is to first, target and assess impacts of interest, as was done with the impact inventory and lampen-flora mapping, and second, identify and document resources of concern, as with the photo inventory and paleo survey. A third, supplemental approach is to identify areas of potential impact, as with the hazard-fragility assessment.

GIS has many advantages for long-term, visitor-impact monitoring, which cannot be accomplished without repeatable methodology and accessible data. Geographic data can be systematically collected in the field with ESRI ArcPad®. GIS data and linked tables can be synthesized and analyzed using ESRI ArcGIS Desktop®, at the same time, hyperlinked photos can be retrieved and reviewed by location. GIS is a valuable tool for solving problems and making decisions, and its applications for understanding and managing the problems associated with humans in caves should continue to be explored.

Visitor-impact mapping, whether or not it is GIS-based, is only a starting point for protecting cave resources. Visitor-impact data introduce cave managers to significant or potential impacts, once they are identified, protection, mitigation and/or monitoring are the next actions. Some impacts can at least be partially reversed, but many permanently impair unique or nonrenewable resources. Further studies and/or scientific analyses are warranted in instances when prevention may be the only option for mitigation. Only when visitor-impact mapping leads to cave management decisions can it help find the balance between providing for recreation, research and education vs. protecting cave resources.

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## Literature Cited

Bodenhamer, Hans. 1996. Monitoring human-caused changes with visitor impact mapping. pp 28–37 *in* .Rea, G. Thomas, ed. 1996. *Proceedings of the 1995 National Cave Management Symposium*. Spring Mill State Park, Mitchell, Indiana, October 25–28, 1995. Indiana Karst Conservancy, Inc. 318 pp.

Bunting, Benjamin W. and Megan R. Balks. 2001. A quantitative method for assessing the impacts of recreational cave use on the physical environment of wild caves. *Australasian Cave and Karst Management Association Journal*, 44:10–18.

Department of the Interior, National Park Service. 2005. *Oregon Caves National Monument Subsurface Management Plan*.

Horne, Greg. 2006. Cave management guidelines for western mountain national parks of Canada. pp 53–61 *in* G. Thomas Rea, ed. 2006. *Proceedings of the 2005 National Cave and Karst Management Symposium, Albany, New York, October 31-November 4, 2005. NCKMS Steering Committee. 261 pp.*

Kovarik, Johanna and Pat Kambesis. 2006. Cave Resource Inventories: Why are they important? pp 8–14 *in* G. Thomas Rea, ed. 2006. *Proceedings of the 2005 National Cave and Karst Management Symposium, Albany, New York, October 31–November 4, 2005. NCKMS Steering Committee. 261 pp.*

Ohms, Rene. 2003. Using a geodatabase network to determine best travel routes through Jewel Cave. Paper presented at the 2003 National Speleological Society Convention, 4–8 August 2003, Porterville, California.

Sainsbury, Benjamin N. 2005. Crucifixion Cave – The Resurrection: A photo-monitoring GIS procedure to evaluate visitor impacts in the last 15 years. Paper presented at the Eighth Biennial Colorado Plateau Conference, 7–10 November 2005, Flagstaff, Arizona.

Toomey, Rickard S., III. 2006. Paleontology in cave conservation and restoration. Part 2, pp 83–91 *in* Hildreth-Werker, Val and Jim C. Werker (eds.), *Cave Conservation and Restoration*. National Speleological Society, Huntsville, Alabama.